

**AN APPROACH TO A MODEL OF THE VISUAL CORTEX.
DISORDERS OF VISION.**

A. GONZÁLEZ- MARCOS & J.A. MARTÍN-PEREDA

E.T.S. Ingenieros de Telecomunicación
Universidad Politécnica de Madrid

Ciudad Universitaria

28040 MADRID

Tel.: 91. 336.7304

Fax.: 91. 336.7319

e-mail: JAMP@ TFO.UPM.ES

Correspondence should be addressed to Prof. J.A. Martín-Pereda

AN APPROACH TO A MODEL OF THE VISUAL CORTEX. DISORDERS OF VISION.

I.- INTRODUCTION

One of the most challenging problems that must be solved by any theoretical model purporting to explain the competence of the human brain for relational tasks is the one related with the analysis and representation of the internal structure in an extended spatial layout of multiple objects. In this way, some of the problems are related with specific aims as how can we extract and represent spatial relationships among objects, how can we represent the movement of a selected object and so on. The main objective of this paper is the study of some plausible brain structures that can provide answers in these problems. Moreover, in order to achieve a more concrete knowledge, our study will be focused on the response of the retinal layers for optical information processing and how this information can be processed in the first cortex layers. The model to be reported is just a first trial and some major additions are needed to complete the whole vision process.

II.- MAIN FEATURES OF THE RETINAL MODEL

2.1.- PREVIOUS STUDIES

Most neurophysiological studies of visual cortex have been directed at understanding how neurons represent information in the retinal image. Recently, however, more attention has been directed at recording from behaving animals in order to study extraretinal representations in visual cortex.

There are many reasons to believe that different regions of visual cortex may be specialized for various types of extraretinal signals. Chief among these is the high degree of specialization seen in the processing of signals that arise from the retina. The cortex of the macaque monkey contains more than 30 distinct visual areas. Each of these areas has its own, sometimes limited, representation of the visual field and is believed to play a distinct role in processing visual information. Cortical visual areas appear to be organized in a hierarchical fashion (Fig. 1), with areas on higher levels responsible for representing increasingly complex types of visual information. For example, while neurons in the primary visual area, V1, respond strongly to the appearance of edges in particular orientations, many neurons in higher stages of processing in the temporal lobe respond only to complex patterns or forms, including faces or hands.

In addition to this hierarchical arrangement, there is also parallel segregation in visual cortex. Large regions of visual cortex appear to be segregated into two streams of processing, the temporal and the parietal pathways. Each of these pathways includes different visual areas and is believed to be involved in different types of visual processing. The parietal pathway, which includes many areas containing neurons with a high degree of direction selectivity, is considered important for the analysis of motion and spatial relationships. The temporal pathway includes other areas whose neurons appear more selective for pattern or form.

Several works have been published in the last years concerning the modelling and

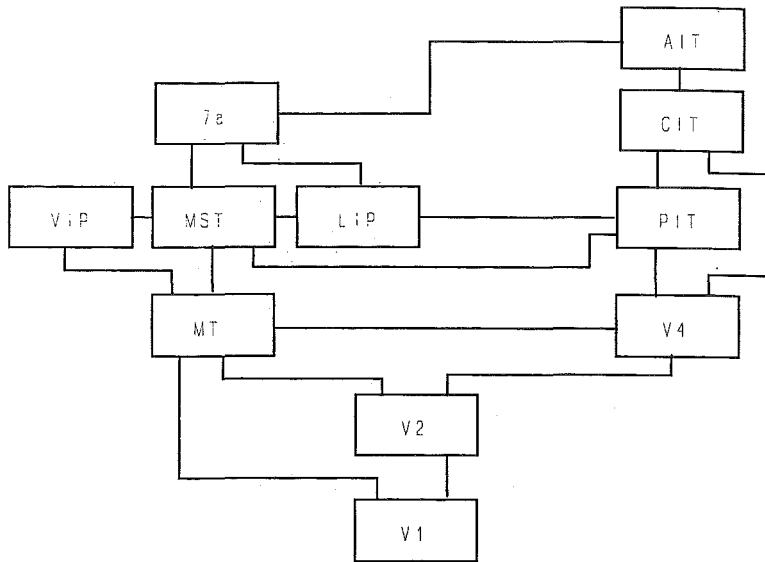


Fig. 1 The organization of monkey visual cortex: parietal and temporal pathways. [Ref. 6].

implementation of the visual cortex operation. Most of them present simple neurons with just two different responses, namely inhibitory and excitatory. Some of the different types of visual cortex cells are simulated in these configurations

Another approach has been reported by us. Based on a previously studied cell structure [1]-[2], the five types of cells present at the vertebrate retina and their intracellular response, as well as their connections with each other, were simulated [3]-[4]. The main scheme of our configuration is shown in Fig. 2. As in the retinal structure, it is divided into four layers: receptor, outer, inner and ganglion cell layers. These four layers are composed by five different cell types: receptor (rod and cones), bipolar, horizontal, amacrine and ganglion cells.

The response given by receptors, bipolar and horizontal cells are just hiper or depolarizing potentials, with a close relation, in shape and time length, to the input light signal. But another type of function is performed by amacrine cells. They give a periodic signal, with period and pulse length depending on the characteristics of the signals coming from bipolar cells. The composite signals from bipolar and amacrine cells arrive to the ganglion cells from where the final signal is obtained.

Ganglion cells differ from all other types of retinal interneurons, except the above mentioned amacrine, in that they respond to light with repetitive spike discharges. Like bipolars, ganglion cells often have receptive fields consisting of a centre region with an antagonistic surround, many of them having in addition the property that they respond only transiently when retinal illumination is suddenly changed from one level to another. Sometimes a transient burst of firing is found in response to an increase of illuminations (an 'on-response'), and sometimes to a decrease ('off-response'); and sometimes one may find a burst response both at the beginning and end of a period of steady illumination (an 'on-off response'). A cell with an on-response at its centre will normally show an off-response in its surround, and viceversa and they show on-off responses in intermediate regions. The

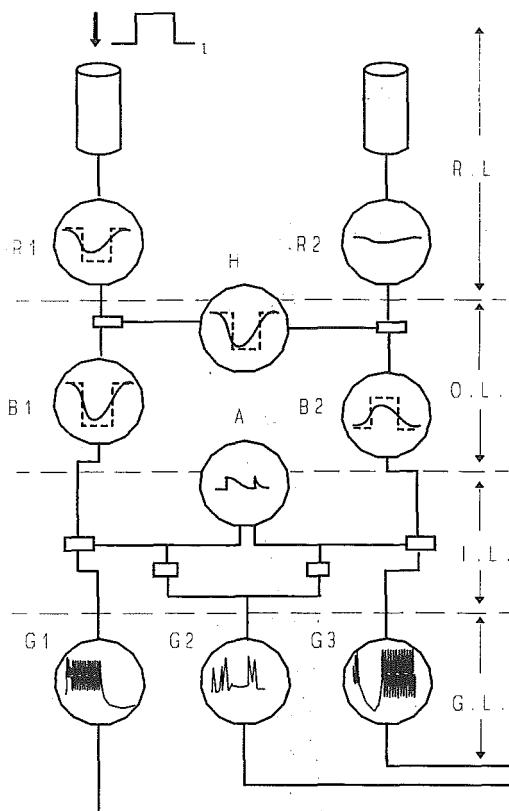


Fig. 2.- Intracellular responses of the various retinal cells and their connections with each other.

different behaviour is obtained. Depending on the value of the time delay, an oscillatory output can be obtained from a constant optical signal input. Period and length pulses are depending on delay values, both external and internal. A chaotic signal is also obtained under certain circumstances.

With the above considered facts, a configuration similar to the one proposed by Dowling [5] to summarize the activity of the various retinal cells was implemented. As it can be seen in Fig. 2, the receptor on the left is illuminated with a brief flash of light imposed on a dim background which illuminates both receptors, R_1 and R_2 . Their control signals make them to operate with NAND functions. Same function is performed by the horizontal cell H . Bipolar cells, B_1 and B_2 , operate as AND or NAND functions according to the control signals imposed by the previous layer. Outputs from bipolar cells act on amacrine and ganglion cells.

difference with respect to bipolar cells is the result of feedback inhibition from the amacrine, whose responses are very similar to those of ganglion cells and have the right sort of connections for mediating lateral and self-inhibition of the type that would explain the time-course of the ganglion cell responses.

These five cells have been implemented with an Optical-Processing Element, **OPL**, reported previously by us. As it was shown, this structure is able to process two optical input binary signals, being the output two logical functions. The type of processing is related to the eight main Boolean Functions. According to the value of two external control signals, any one of these functions can be obtained from the structure. Moreover, if a delayed feedback from one of the two possible outputs to one or both of the inputs is introduced, a very

In the studied case, three were the final outputs from the proposed structure. The first one is a train of light pulses being its length the same one as the input flash. The third one is always a sequence of short pulses; only when it was light at the input, pulses disappear. Finally, the second one gives a very short train of pulses at the beginning and at the end of the initial flash.

Our single configuration was implemented, partly, with optoelectronic techniques. A computer simulation gave us the behaviour of the whole cell.

2.2.- RESULTS CONCERNING THE LOWER VISUAL CORTEX

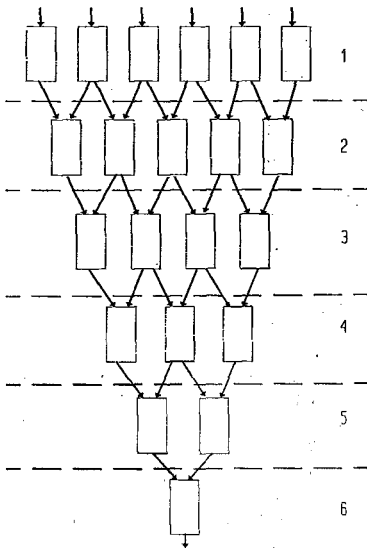


Fig. 3.- Simplified proposed hierarchical arrangement for the visual cortex.

our case, fourteen are the possible pairs of Boolean logic functions obtained as outputs. This situation gives the possibility to implement any type of synapses between neurons, both excitatory and inhibitory, as well as oscillatory behaviors. The reported architecture is just a two dimensional configuration without lateral branches corresponding to other possible functions. Because the whole information corresponding to the input image is transferred to a train of pulses in each type of ganglion cells, in order to process such an information, a different type of architecture will have to be implemented for each one of the input data (colours, shapes, motion, edges, and so on).

We have considered in this occasion just one of the two possible outputs from the OPLs. Moreover, just one type of logic function was adopted, namely, XOR. With these boundary conditions, our structure is able to recognize asymmetries in the input signals. If any

A further step has been undertaken based on the above obtained results. Moreover, this new work is the first step towards a complete simulation of the final structure shown in Fig. 1. In this case, a simple linear configuration has been adopted for the first layer of our model. It corresponds to the possible signals coming out from ganglion cells. These signals will be the result of the corresponding input data impinging onto the receptors. They will give information about time length of the input light pulse and, in our linear case, number and type of receptors with incoming light. This number has a close correspondence with the spatial length of the signal.

These signals are compared at a second layer, in the way shown in Fig. 3. Boxes correspond to the previously mentioned OPL cells. Output data are compared at the third and following layers in the same way than before. The process keeps going on until it reaches layer 6 where there is just one output.

The possibilities from this architecture are as many as possible logic functions are able to perform the OPLs. In

type of symmetry is present on the signal impinging onto the first layer of cells, a "1" will be obtained at the output. On the contrary, asymmetries will give rise to a "0" at the final cell. Many other features could be implemented with similar configurations.

2.3.- DISORDERS OF VISION

As it was shown [7], if a certain feedback is added to the OPL, when external or internal delays are varied according to certain rules, a chaotic process could be obtained. This new state may appear from many different sources. In the case of an optoelectronic simulation, a variation in the nonlinear device parameter values can be the origin of these changes. For example, they may be originated from a certain increase in temperature or a bias fluctuation.

In the reported case, the output from layer 6 could vary from "1" to "0", or viceversa, in chaotic way. Because this signal gives information about the external world, no true information is obtained. Hence, a malfunction at a certain layer of the cortex would give rise to disorders of vision. A computer simulation has been developed.

III.- CONCLUSIONS

We have obtained, with the reported architecture, a possible way to simulate the first layers of the visual cortex. The present configuration is able to process almost any type of information acting on the retinal receptor. The final output is a bit of information that could be considered as a bit of knowledge. Some other possibilities will be reported as well as a possible way to explain vision disorders.

IV.- REFERENCES

- [1] **González-Marcos, A. & J.A. Martín-Pereda.** "Quasi-chaotic digital behaviour in an optically processing element". *SPIE*, 2038, 67-77. (1993).
- [2] **Martín-Pereda, J.A. & A. González-Marcos.** "Optical Programmable Processing Element using Optical Fibers". *IEEE Lasers and Electro-Optics Society, LEOS'92*. Boston, 15-20 November, 1992.
- [3] **Martín-Pereda, J.A. & A. González-Marcos.** "An Approach to Visual Cortex Operation: Optical Neuron Model". *CLEO/Europe-EQEC'94*. Amsterdam, 28 August-2 September, 1994.
- [4] **González-Marcos, A. & J.A. Martín-Pereda.** "A Model of Amacrine and Ganglion Cells for Optical Information Processing". *LEOS'94*. Boston, October 31 - November 3, 1994.
- [5] **Maunsell, J.H.R. & V.P. Ferrera.** "Attentional Mechanisms in Visual Cortex". In *"The Cognitive Neurosciences"*, ed. M.S. Gazzaniga. The MIT Press. London. 1995.
- [6] **Dowling, J.E.** "Organization of the vertebrate retina" *Investigative Ophthalmol.* **9**. 655-80, 1970.
- [7] **A. González-Marcos & J.A. Martín-Pereda.** "Sequences of bifurcations and transition to Chaos in an Optically-Processing Element". "Optical Computing". *OC'94*. Edinburgh. UK. August 22-25, 1994.